(51) International Patent Classification 5 :		(11) International Publication Number:	**WO 92/08408**
A61B 8/02	**A1**	(43) International Publication Date:	29 May 1992 (29.05.92)

(54) Title: BLOOD POOL IMAGING AND ANALYSIS USING ULTRASOUND
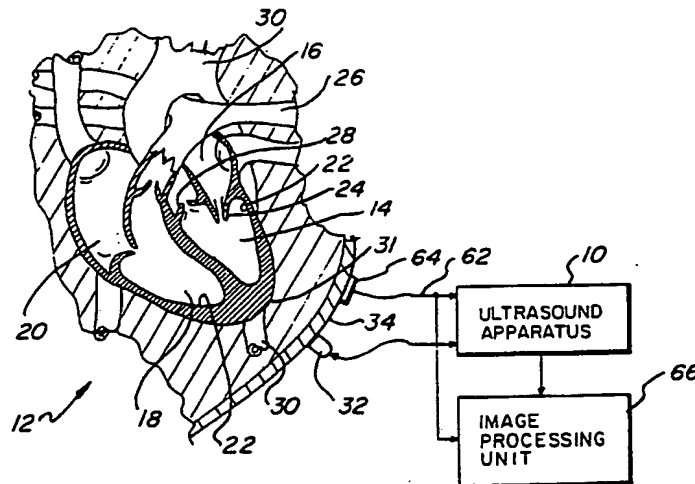
(57) Abstract

A blood pool imaging and analysis technique and apparatus (66) uses ultrasound to examine areas of interest within the human body. The Doppler effect is used to determine the velocity of blood and tissue movement. Color flow imaging is used to display the moving blood pools and tissue by representing movement toward the transducer (32) as one color, movement away from the transducer (32) as a second color and movement which is outside of the sampling limits as a third color. Since the blood pool movement generally exceeds the rate at which the heart (12) or organ walls (22) move in creating the blood movement, the sampling limits can be adjusted so that the blood pool movement is outside of the limits. The resulting image of the blood pool movement, in the third color. can be used to calculate heart function parameters such as the ejection fraction.

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-BLOOD POOL IMAGING AND ANALYSIS USING ULTRASOUND-.

This invention relates to the use of ultrasound
for medical purposes, and more particularly, to a
5   noninvasive diagnostic technique using ultrasound to
image moving pools of blood in internal organs of
the body to evaluate the function of such organs,
especially the human heart.

Background of the Invention

10   The human heart is made up of four chambers: the
left and right atria and the left and right
ventricles. Simply put, the right atrium receives
blood from the veins of the body and the right
ventricle pumps this blood through the pulmonary
15   arteries to the lungs. The left atrium receives
blood from the lungs through the pulmonary veins and
the left ventricle pumps this blood through the
aorta systemically to the tissues of the body.

The left ventricle (LV) is commonly analyzed by
20   physicians in order to determine the presence of
coronary circulatory problems in a patient.
Coronary artery disease can be diagnosed through
observation of the functioning of the left
ventricle. Roughly eighty percent of all heart
25   disease is coronary artery disease.

While as many as three hundred different
parameters regarding heart functioning are known to
exist, the most common and widely used parameter for
evaluating the LV function is the ejection fraction.
30   The ejection fraction (EF) is the percentage of
blood ejected or displaced from the LV with each
contraction. A fully contracted ventricle is in
what is known as the systolic state, while a fully
dilated ventricle is in the diastolic state.
35   Therefore, the EF equals the difference in blood

volume in the LV between the systolic and diastolic
states divided by the blood volume in the LV in the
diastolic state. Thus,

5
$$EF = \frac{V_D - V_S}{V_D} \times 100$$

where   EF is expressed as a percentage
V_D = blood volume in LV in diastolic
10   state
V_S = blood volume in LV in systolic
state.

An EF in the range of fifty to sixty percent can be
15   expected from a normal, healthy heart. An EF in the
range of thirty to forty percent is a sign of
improper functioning, while an EF of twenty percent
is accompanied by serious consequences.

    LV functioning has been observed by ultrasound
20   detection of the heart wall, known as the
endocardium. However, the observation of the
dilation and contraction of the LV is an indirect
method of measuring the ejection fraction, since the
EF is a percentage of blood ejected. This indirect
25   method is inaccurate because of poorly defined
endocardiums, ventricular hypertrophy and misshapen
cardiac chambers, i.e. aneurysms. Therefore, to
accurately analyze LV functioning the volume of
blood must be measured directly.

30   The field of nuclear imaging or nuclear medicine
has been used to image a blood pool in the LV.
Nuclear imaging is an invasive diagnostic technique
which requires an injection of a radioactive isotope
into the blood stream. This radioactive isotope is
35   normally tagged or attached to a pharmaceutical drug
before injection into the patient's blood stream.
The isotope radiates nuclear energy which can be
detected by a sensor, commonly known as a gamma
camera, pointed at the area of interest, in this
40   case the LV. When averaged over up to one thousand
heart cycles or over twenty minutes, this nuclear

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imaging technique can produce an image of the blood
pool in the LV both in the systolic and diastolic
states. These images can either be manually
analyzed to determine the EF and other LV functional
5   parameters, or the images can be automatically
analyzed by an image processor.

To analyze a "black-and-white" image with an
image processor, the image is divided into an array
of rows and columns of hundreds of picture elements,
10   or pixels. Each pixel is assigned a value
representing the "shade of gray" in that pixel.
These values can then be analyzed by the image
processing computer, with the use of known pattern
recognition algorithms, to determine the boundaries
15   of the blood pool in the LV. Once the boundaries
are determined, known estimation algorithms are
utilized to estimate the three-dimensional volume of
the blood pool from the two-dimensional image of the
blood pool. The EF and other LV functional
20   parameters can then be calculated.

There are several drawbacks to nuclear imaging to
determine LV function. The most serious is the
invasive nature of injecting a radioactive isotope
tagged to a pharmaceutical drug into the blood
25   stream. The technique is also inaccurate due to the
need to average the image over a twenty minute
period. During this period the patient may move or
the heart cycle or rate may speed up or slow down.
Either of these two changes will cause inaccuracies
30   in the image.

A second invasive diagnostic technique involves
the use of a catheter to inject a dye into the
bloodstream near the heart. This dye is selected to
be absorbent to x-ray energy. Standard x-ray
35   techniques are then used to image the blood pool in
the LV by transmitting x-ray energy through the LV
from one side of the body while detecting x-ray

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energy on the other side of the body. The dye in
the LV absorbs the x-ray energy and creates a shadow
in the image which can thereafter be evaluated.
Again, this invasive method has the disadvantage of
5   injecting a foreign substance into the blood stream.
Furthermore, x-ray techniques work best for still
images and not dynamic or moving images.

In addition to the use of ultrasound to observe a
moving wall of the heart, ultrasound has been used
10   to observe or measure the flow of blood. By
definition, ultrasound is a sound pressure wave
having a frequency greater than twenty kilohertz.
Most ultrasound sensors utilize the Doppler effect
to sense motion. In simple terms, the Doppler
15   effect is the frequency shift resulting from the
reflection of a constant frequency signal off of a
moving object. An object moving toward the signal
will reflect a higher frequency signal. Conversely,
an object moving away from the signal will reflect a
20   lower frequency signal. The magnitude of the
frequency shift is proportional to the speed of the
moving object. Stationary objects will not change
the frequency of the reflected signal.

In the case of monitoring blood flow with
25   ultrasound, the moving objects are the red blood
cells in the bloodstream. An ultrasound transducer,
for converting an electrical signal to transmitted
ultrasound and for converting received ultrasound to
an electrical signal, is placed over the area of
30   interest in a patient's body. This area of interest
for observation of LV functioning with ultrasound is
the bottom or apex of the heart. A two-dimensional
image is generated by sweeping the transmitted
direction of the ultrasound through a fixed angle,
35   resulting in a wedge or sector shaped image.

It is common to use color video to represent the
image received by the ultrasound sensor. The

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movement of blood toward the transducer (a positive
Doppler frequency shift) has commonly been
represented by red, an arbitrarily selected but
universally applied color. The movement of blood
5   away from the transducer (a negative Doppler
frequency shift) has commonly been represented by
blue, another arbitrarily selected color. Slow
moving or stationary objects, including blood, are
represented by grey. Greater rates of movement are
10   represented by saturated shades (more white), and
slower rates of movement are represented by less
saturated shades (less white). Hence, such color
ultrasound systems are known as color flow imaging
systems.
15   One of the important aspects of color flow
imaging involves sampling theory. Sampling theory
reveals that the accuracy of the Doppler frequency
shift determination is proportional to the time
spent observing or measuring the movement of the
20   object creating the shift. Since, as mentioned
previously, the magnitude of the frequency shift is
proportional to the speed of the moving object, slow
moving objects will have small frequency shifts.
Therefore, relatively more samples will be needed to
25   accurately determine the speed of slow and
stationary objects. The dynamics of the heart are
such that the endocardium of the heart moves at a
velocity which is believed to be in the range of ten
centimeters per second (with some variation
30   depending on exercise level and physical condition),
while blood flow is at a velocity in the range of
thirty to one hundred twenty centimeters per second.
Flow rates near ninety centimeters per second typify
leaks from valves and holes in vessels and chambers
35   of the heart.
     The color flow imaging systems can be optimized
to look for velocities of a particular magnitude.

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When a moving object with a velocity outside of the
limits of a selected range is encountered, there
will exist an uncertainty as to the measurements of
this out-of-limit velocity due to sampling theory
5   limitations. When this occurs the movement is
portrayed by a green color mixed with either red or
blue, as appropriate. The green color was
arbitrarily selected, and although not universal has
become somewhat of a standard in the industry.
10   Increasing degrees of uncertainty cause increasing
amounts of the red or blue colors to be replaced
with green. Adding the green to red obtains shades
of yellow, and adding the green to blue obtains
shades of cyan.
15   Since color flow imaging systems have primarily
been used to detect leaks and defects or to measure
the speed of blood flow, the velocity range is
normally set to a maximum setting for observation of
LV functioning, e.g. from thirty to one hundred
20   twenty centimeters per second. This setting is then
adjusted in an effort to reduce the amount of green
in the object of interest. Such common usage has,
however, not resulted in a significant capability to
evaluate LV function including EF and other heart
25   functional characteristics involving the movement of
blood pools.
It is with respect to these and other
considerations that the present invention has
evolved.
30   Summary of the Invention
The present invention uses ultrasound as a
noninvasive diagnostic technique for imaging moving
blood pools in the heart or another organ, by
adjusting the movement velocity limits of the
35   ultrasound apparatus to a minimum setting so that
the moving organ or endocardium is within the
desired limits and the faster moving blood pool is

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out-of-limits. This adjustment causes the blood
pool, which is moving at a much greater and out-of-
limit rate, to be displayed as a different color
(primarily green) than the organ or endocardium.
5   The resulting blood pool image is distinguishable
from the remainder of the image by its out-of-limit
color and can be analyzed to determine the size of
the blood pool movement and other functional aspects
of the organ or heart, including the ejection
10 fraction.

The present invention has the advantage of
providing an image of blood pools in the heart
without injecting foreign agents into the
bloodstream. The present invention transmits
15 ultrasonic vibrations into the body as opposed to x-
rays, dyes, radioactive isotopes and pharmaceutical
drugs. In addition, the present invention achieves
an accuracy level better than or comparable to
previous methods in much less time than with
20 previous methods. Furthermore, the present
invention can automatically and directly calculate
organ or heart functional parameters from a
measurement of the blood pool rather than a
measurement of the sizes of chambers of the heart or
25 organs containing the blood pool.

According to a preferred aspect of the present
invention, a series of pulses of ultrasonic signals
of a predetermined frequency are transmitted into a
patient's body and reflected off of the moving fluid
30 and tissues in the patient's body. The reflected
signals are used to calculate the range, position
and velocity of the fluid and tissues. The velocity
is calculated by use of the Doppler effect. The
movement of the fluid and tissues in the area of
35 interest can then be categorized by velocity, thus
defining regions of distinct velocity. These

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regions can then be displayed as a color video image
with distinct colors for distinct velocities.

A more complete understanding of the nature of
the present invention and its advantages and
5   improvements can be obtained from the following
detailed description of a presently preferred
embodiment of the invention taken in conjunction
with the accompanying drawings, briefly described
below, and from the appended claims.

10   Brief Description of the Drawings
Fig. 1 is a generalized illustration of an
ultrasound apparatus and an image processing unit
according to the present invention by which
ultrasound image information is obtained from a
15   patient to evaluate the function of the patient's
heart, which is also illustrated.

Fig. 2 is a block diagram of a prior art
ultrasound apparatus, such as that shown in Fig. 1.

20   Fig. 3 is a block diagram of an image processing
unit, shown in Fig. 1.

Fig. 4 is a flow diagram illustrating the
practice of the present invention in conjunction
with an image processing unit and/or an ultrasound
25   apparatus, shown in Figs. 1, 2 and 3.

Fig. 5 is a generalized illustration of the left
ventricle of the heart shown in Fig. 1, with an area
bounded by shorter dash lines representing blood
pool movement during systolic conditions, with an
30   area bounded by longer dash lines representing blood
pool movement during diastolic conditions, and with
the area between the shorter and longer dash lines
representing the amount of fluid ejected from the
left ventricle during a heartbeat.

35   Detailed Description of the Preferred Embodiment
Referring to the drawings and specifically to
Fig. 1, the present invention involves the use of an

echocardiographic or ultrasound apparatus 10 for
determining the performance of an individual's heart
12. As will be discussed more completely below, one
of the major functions of the present invention is
to evaluate the blood flow movement within the
various chambers of the heart, which include the
left ventricle (LV) 14, the left atrium 16, the
right ventricle 18 and the right atrium 20, all of
which are defined by the muscle wall or endocardium
22 of the heart 12. By observing blood flow
movement within the heart chambers, various heart
functions may be evaluated.

    As previously mentioned, one of the most
prevalent indices used for evaluation of heart
function is the ejection fraction. Determining the
ejection fraction (EF) takes into account the
general condition of the left ventricle 14 or
effectiveness of the endocardium 22 in forcing the
blood from the LV. The EF is used to represent the
heart's functional condition in a single number.

    The present invention offers significant
advantages and improvements in using ultrasound
imaging to evaluate the left ventricle ejection
fraction and many other heart functions involving
blood flow and movement. In general the noninvasive
imaging technique of the present invention involves
considerably less risk to the patient than previous
nuclear imaging and invasive catheterization
techniques, while offering comparable or better
analysis results of heart performance.

    The typical ultrasound apparatus 10, which is
also shown in generalized form in Fig. 2, can be
used in practicing the present invention under the
circumstances explained below. In general the
ultrasound apparatus 10 includes a transducer 32
which is positioned on the skin 34 of a patient.
The transducer 32 transmits ultrasound pulses in

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response to the application of electrical pulse
signals 36 from a transmitter 38. The transmitted
ultrasound pulses project into the patient's body
where they encounter various structures, tissues,
5   components and particles that cause a reflection or
"echo" of the projected ultrasound pulses back to
the transducer 32. The reflection itself induces
changes in the ultrasound echo compared to the
transmitted ultrasound pulses, and the echo
10 ultrasound signals contain information regarding the
location and movement of the structures, tissues,
components and particles which cause the echo. The
transmitted pulses and the received echo ultrasound
signals form a beam 40 which scans through an
15 angular sector 42 in a plane. The scanning effect
is achieved by a scan signal 44 which is also
transmitted from the transmitter in synchronism with
the pulse signal 36. The scan signal causes either
a mechanical movement of the transducer 32 or an
20 electrical deflection of the transmitted pulses from
the transducer.

       The ultrasound echo is received by the transducer
32, and the transducer converts the echo into an
electrical echo signal 46. The echo signals 46 are
25 applied to a receiver and digital scan converter 48.
The receiver and converter 48 utilizes the
information from the echo signal, the pulse signal
36 and the scan signal 44 to develop the ultrasound
image information which will be presented, usually
30 in enhanced form by the ultrasound apparatus 10.
The relative timing relationship of the pulse and
echo signals are employed to develop range or
distance information by which to obtain information
only from a selected range of interest or location
35 in the patient's body. The frequency difference
between the ultrasound frequency of the transmitted
pulses and the received echo signals is

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ultrasound imaging. A variety of known algorithms
are used to determine from the signals recorded in
memory, the edges and other characteristic features
represented by the data. These algorithms are known
5   by various titles, and are readily available for use
by those skilled in this field. In any event, the
computer typically utilizes such algorithms under
software control to derive the enhanced images.
Usually the image information will be enhanced
10   before it is recorded permanently in memory.

    A display 56 visually presents the image
information to the user. Typically the display will
be a CRT or raster scan device, and the user may
manually select a variety of information to be
15   displayed. The information to be displayed is
selected from the memory 54, and it is supplied to a
video converter 58 which is also connected to the
bus 50. The video converter 58 converts the
information from digital form to an analog video
20   format form and supplies it to the display 56. The
video converter may supply the analog video signals
in one of a variety of different known video
formats. In addition, the analog video signals
representative of the image information may also be
25   stored in a video storage device or recorder 60, for
subsequent analysis or use.

    The transmitter 38 is also connected to the bus
50 and can also be controlled by the computer, if
desired, when generating the pulse and scan signals
30   36 and 44, respectively. The pulse and scan signals
are generated continuously and are not synchronized
to the patient's heart function. However, for
echocardiographic applications it is desirable to
synchronize or trigger the storing of the image
35   information relative to the heartbeat of the
patient, and for this purpose a conventional
electrocardiograph (EKG) signal 62 is supplied from

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an electrode 64 attached to the patient (Fig. 1).
The EKG signal 62 is supplied to the bus 50 through
a conventional I/O adapter 65. The signal 62
represents the electrical signal conducted to the
5   nerves of the heart in order to cause the muscles to
contract and beat. Typically the pulses forming
each angular scan will be triggered relative to the
R or major wave portion of the EKG signal 62.
Occasionally, there are periods of arrythmia or
10   variation from the normal rhythm of the heart. The
processor is able to detect this arrythmia from the
EKG signal 62 and not store or analyze images during
such periods, or otherwise mark or note that the
data for those images is subject to discrepancies.

15   By triggering the storing of image information at
predetermined time intervals during each heart beat,
frames or still images of the heart in a number of
conditions are obtained. For example, if ten frames
are obtained during each heartbeat, ten image frames
20   will represent in still motion the condition of the
heart during a single beat. Obtaining multiple
frames of image information in this manner allows
the frames to be separately examined and analyzed.
Each frame is constituted of the composite of all of
25   the digital signals recorded in memory 54 derived
from the scan.

While the functionality and information available
from an ultrasound apparatus 10 are well known and
conventional, certain of these functions which are
30   of importance to the present invention will be
briefly described below.

The ultrasound apparatus has the capability of
establishing a particular range or depth or region
of interest within the interior of the patient's
35   body over which signals will be developed to provide
an image of the region of interest. This region of
interest is determined by correlating and

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considering only those signals received within a
predetermined range of time delays after the
transmission signal is delivered. The signals
developed in this region of interest relate to the
5   physical location or position within the patient's
body.

Another function available from the ultrasound
apparatus is the ability to determine movement or
flow. The movement or flow is created when a body
10   or particle which the ultrasound strikes is moving
either toward or away from the probe 32. The well
known Doppler effect occurs, which results in a
change in frequency of the reflected or echo signal.
The degree to which the frequency is changed is
15   representative of the rate of movement. Movement
toward the transducer or away from the transducer is
determined by the change in frequency of the
received signal relative to the transmitted signal.

20   A further well known function of the ultrasound
apparatus is the ability to select a limit or range
of movements or flows to which the ultrasound
apparatus will be primarily responsive. A typical
range of movements from approximately six
25   centimeters per second up to as great as one hundred
twenty centimeters per second can be selected.
Selection of the range of flows or movements result
in changing the rate of sampling or transmission
pulse delivery rate. When movements in the
30   relatively high range are desired, a slower sampling
rate is used, because more adequate information will
be obtained as a result of the high rate of movement
of the target and the relatively low sampling rate.
On the other hand, when the relatively slow
35   movements or flows are to be measured, a higher
sampling rate must be selected. The rate of
sampling relative to the desired range of movements

or flows are related to one another by conventional
sampling theory, generally referred to as the
Nyquist limit. Nyquist theory relates to the rate
of sampling relative to the rate of movement of a

5   target in order to obtain full information relative
to the movement of the target. In most conventional
ultrasound apparatus, the range of movements or the
Nyquist limit is generally variable from
approximately as low as 8 centimeters per second, to

10   as high as 100 centimeters per second.
        Still another function of conventional ultrasound
apparatus is to assign color to the display of
information relative to the movements or flows.
This is sometimes referred to as "color flow". For

15   example, a target which moves at a particular rate
toward the transducer is conventionally assigned a
red color, while a target which moves away from the
probe is assigned a blue color. The brightness of
the red and blue color is intended to represent the

20   amount or rate of movement. Brightness is
controlled by mixing white with the red or the blue.
A very saturated red color has a significant white
component and represents a rapid movement toward the
probe, and a very saturated blue also has a

25   significant white component and represents a rapid
movement away from the transducer. Slow or moderate
movement toward the probe and slow or moderate
movement away from the probe will result in
relatively less saturated shades of red and blue,

30   respectively, in which there is a lower amount of
white. Accordingly, by the assignment of the
colors, the operator not only obtains information
regarding the structure and position due to the
depth or region of interest adjustment, but also

35   obtains information regarding the movement of that
structure or target toward or away from the
transducer by the color and information regarding

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the rate of movement by the brightness of the color.

Of course, not all of the particles which the
ultrasound beam intercepts will move within the
5   desired range of flows or movement. Those which are
in excess of the upper limit of the range create
additional signal effects. These additional signal
effects are referred to herein as out-of-limit
responses, and are typically referred to in
10   conventional ultrasound terminology as aliasing,
variance and phase shift. In general, aliasing
relates to the degree to which a received signal
exceeds the upper limit of the desired selected
range of movement velocity. In general, variance
15   relates to the degree to which all signals vary with
respect to one another. Phase shifts relate to
reflections of the signals in such a way that the
signal itself is shifted beyond predetermined limits
of acceptable time phase variation. In general,
20   these out-of-limit responses relate to effects
resulting from the reflection of ultrasound signals
from movements beyond those within the selected
range of movements. The out-of-limit response in
general terms relates to the validity of the
25   information obtained in the selected range of
movements.

Of course, since not all of the signals are
reflected at the selected range of movement or flow,
due to the dynamic characteristics of many particles
30   and structures within the human body, color has also
been assigned to represent the gross extent of the
out-of-limit response characteristics or
uncertainty, in most conventional ultrasound
apparatus. In general, the manner in which
35   aliasing, variance and phase shifts are combined to
obtain a single representation of the out-of-limit
response characteristics are to a large measure

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proprietary in most conventional ultrasound
machines, but nonetheless, such representations are
available on the vast majority of conventional
ultrasound machines. This quantity of out-of-limit

5   response is assigned a color which is displayed in
conjunction with the red and blue colors
representative of the. desired movement toward and
away from the transducer, represented by the red and
blue. Usually the color green is assigned to

10   represent the extent of out-of-limit response. In
addition, the saturation level of green is also
changed to represent the magnitude of the out-of-
limit response. In most conventional ultrasound
machines the green is then combined with the red and

15   blue colors to provide a further visual indication
of the extent to which the measured range of
movement or flow is subject to out-of-limit response
or validity. Adding the green to red obtains shades
of yellow, and adding the green to blue obtains

20   shades of cyan.
Thus, from the foregoing information, the
ultrasound apparatus 10 creates a display at 56 of
the internal structure within a particular depth or
range of interest, an indication of a rate of

25   movement within a preselected velocity range within
that range of interest, and an indication of the
validity of that velocity, all on the single
display, by use of the display characteristics known
as color flow imaging.

30   The present invention may be practiced by using a
conventional ultrasound machine 10, such as the
ACCUSON 128 machine, with modifications primarily in
software to achieve the additional functionality
described below. Alternatively the invention may be

35   practiced by connecting a separate image processing
unit 66 to the ultrasound apparatus 10 as is shown
in Fig. 1. The image processing unit 66 is shown in

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Fig. 3 and it will be connected so as to receive a
video display signal at 68 from the ultrasound
apparatus 10 as shown in Fig. 2 to obtain the
signals supplied to the display 56. By accessing
5   the computer memory 54, the image processing unit
has the ability to use the stored image information
in order to process it in accordance with the
present invention. As will be appreciated from the
following description, the image processing unit 66
10   is essentially duplicative of the inherent
functional capability of a conventional ultrasound
apparatus 10. Thus, the present invention may also
be practiced by providing additional software
functionality within a conventional ultrasound
15   apparatus.
     Details regarding the conventional components of
the image processing unit 66 are shown in Fig. 3.
The video display signal 68 is initially applied to
a video format selector and digital scan converter
20   70. The video format selector of the unit 70
converts the video format of the video display
signal 68 supplied by the ultrasound apparatus to an
appropriate video format for image processing. This
video display signal 68 is commonly in one of three
25   standard video formats, NTSC, SVHS or RGB. The
video format selector of the unit 70 converts the
standard video format into a standard component
video format such as YUV, RGB, R-Y B-Y, or HSI. The
digital scan converter of the unit 70 converts the
30   standard component video format into digital form
and applies it to a bus 72. The digital signals may
be read into a memory 74 where they may thereafter
by acted on by a processor 76 operating under the
control of software recorded in the memory 74 to
35   achieve the functionality of the present invention.
The processor 76 and the memory 74 form an image
processing unit computer which may be used to

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practice the present invention. The generalized
diagram of the memory 74 (as is the memory 54 of the
ultrasound apparatus 10, Fig. 2) is intended to
represent all types of memory, such as main
5   processor memory, scratch pad memory, RAM and the
like necessary to contain the software and data for
the processor 76 to achieve the processing functions
described herein. As discussed previously in
conjunction with Fig. 2, an EKG signal 62 may be
10 supplied to the bus 72 through a conventional I/O
adapter 77.

   A display 78 is available to present the image
information obtained. The image information may be
obtained from the memory 74, or from information
15 obtained from the processor 76 or from information
obtained directly from the selector and converter 70
over the bus 72. In all cases, however, a video
converter 80 converts the digital data into a video
signal 82 which drives the display 78.

20   The practice of the present invention for
determining heart function, and for determining left
ventricle function and particularly for determining
left ventricle ejection fraction is illustrated by
the flow chart shown in Fig. 4. Many of the steps
25 illustrated in the flow chart shown in Fig. 4
utilize the conventional ultrasound techniques and
functionality previously described in conjunction
with Figs. 1 to 3, and hence will be only briefly
described in conjunction with Fig. 4. Steps
30 involved in practicing the preferred embodiment are
described and shown with the aid of reference
numbers in Fig. 4.

   The functionality starts (100), and the first
step thereafter is to position the probe (102) in
35 order to observe a desired part of the patient.
Thereafter, color flow is selected (104) by the
operator manually selecting this functionality from

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the ultrasound apparatus. In addition, the operator
manually selects the depth or region of interest
(106) over which the ultrasound signals will be
effective. Further, the operator selects the
5   velocity flow range (108). When the present
invention is used for determining the left ventricle
ejection fraction or other characteristics having to
do with blood pool movement within the heart, the
velocity range selected is preferably within the
10   same range of velocity as movement of the
endocardium muscle, for example, within the range of
8 to 17 centimeters per second.

Next, a very important step of the present
invention which differentiates the present invention
15   from conventional ultrasound practice is adjusting
the velocity flow range for maximum out-of-limit
response (110). In many regards, the steps 108 and
110 involve setting the Nyquist sampling limit on a
conventional ultrasound apparatus. As noted
20   previously, out-of-limit response relates to
obtaining a maximum of aliasing, variance and phase
shift. In conventional terms, this involves tuning
the ultrasound apparatus to obtain the greatest
amount of green color influence over the red color
25   and blue colors normally presented in most
conventional ultrasound displays. As will be
appreciated, by creating the maximum out-of-limit
response, a color area will be derived in which
maximum blood flow or movement will be revealed.
30   This maximum blood flow movement will not
necessarily be the same as that volume encased
within the endocardium muscle which defines a
chamber or area, for example the left ventricle,
because despite movement of the endocardium muscle,
35   the blood itself may not move significantly
throughout the whole chamber, but instead will only
move in a reduced or diminished sized pool. By

obtaining the maximum out-of-limit response, the
flow rates within that pool will be considerably
higher than the adjusted velocity flow range (step
110), and therefore will achieve maximum out-of-
5   limit response. Blood areas within the chamber
which do not move rapidly but instead move only with
the contracting and expanding wall of the heart,
will be within the adjusted velocity flow range
(step 110) and there will appear only as
10   conventional red and blue colors.

Implementation of the present invention in a
specific, non-conventional ultrasound apparatus may
not require the apparatus to specifically provide
aliasing, variance and phase shift information.
15   Instead, the apparatus can simply determine one or
more of these out-of-limit conditions relative to
the selected limit and attribute to the out-of-limit
condition(s), a specific coloring or designation in
the image.

20   As will be seen from Fig. 5, actual heart
performance is determined by the blood pool which
experiences considerable movement, as will be
revealed by the color associated with the out-of-
limit response.

25   Thereafter, the probe is adjusted (112) to obtain
the desired view, as shown in Fig. 4. For example,
there are a number of different views which are
recognized for measuring heart function, the most
common being the two and the four chamber views.
30   One of the most common views requires the transducer
56 to be positioned at the apex 31 of the heart as
is shown in Fig. 1. Thereafter the probe can be
rotated to provide the desired axis or viewing plane
through the heart to obtain the desired information.
35   Another common view which can be used is the
transesophageal view (not shown) in which the
transducer is placed in the esophagus to orient the

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transducer in a position behind the heart and
thereby obtain a view of the heart from that
position.

After the probe 32 has been appropriately
5   adjusted (112) the ultrasound apparatus is gated in
response to the EKG wave (114) to obtain a series of
frames of data between each heartbeat. For example,
adjusting the frame rate between successive
heartbeats as determined by the EKG wave may range
10   in the number from approximately two to thirty
frames per heartbeat.

The analog signals obtained from each gated frame
are thereafter digitized (116) to obtain digitized
frame signals. The digitized frame signals are
15   thereafter recorded at 118 as framed data along with
color flow information determined by the processor.
Thus the information regarding the frames also
includes color flow information associated with each
bit or pixel which comprises the location by
20   location information defining the frame. The data
associated with each frame may be recorded in memory
74 of the image processing unit 66, or in the memory
54 of a conventional ultrasound apparatus which has
been programmed to additionally operate in
25   accordance with the present invention, or recorded
in a video storage unit 60 in video format for later
use on an image processing unit 66.

Thereafter, the recorded frame data and color
flow information is analyzed by use of any known
30   conventional edge detection or pattern recognition
algorithm embodied in software on a computer, in
order to detect (120) the edges of the moving mass
of blood pool noted by the maximum color associated
with the out-of-limit response. Detecting the edges
35   of the pool of moving blood defines the outline of
the pool of moving blood, as is shown in Fig. 5,
where the outline 122 represents the blood pool

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movement under systolic conditions and the outline
124 represents the blood pool movement under
diastolic conditions.

After the outline of the moving blood pool has
5   been detected at 120, the outlines are used to
calculate the various heart function results (126),
or left ventricle (LV) functioning parameters, using
the edge movement data.

Calculating the results at step 126, again
10   involves the use of a number of selected different
manual or automatic processes. For example, one
manual analysis involves selecting from all the data
frames obtained between successive heartbeats, the
maximum area of the moving blood pool as determined
15   by the edge detection at 120, and the minimum area
of the moving blood pool. By determining the area
of the maximum area and the minimum area, which
correspond to the diastolic and systolic conditions
of the heart chamber, it is possible to estimate the
20   maximum and minimum volume of the moving blood pool
in order to calculate the ejection fraction. The
ejection fraction is simply the difference between
the maximum and minimum volumes divided by the
maximum volume. This ejection fraction can be
25   calculated manually using the images presented at
the display or can be calculated automatically by
computer processor. Calculation of the
maximum/minimum areas may also be accomplished as
simply as counting the number of pixels within each
30   area defined by the detected edges.

The estimation of the volume of the moving blood
pool from a two-dimensional cross-sectional area
involves one of several known methods. One involves
the assumption that the LV is in the shape of a
35   prolate ellipsoid. The volume of a prolate
ellipsoid can be calculated from the length, height
and width of the ellipsoid. A second method for

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estimating the volume of the moving blood pool does
not rely on the assumption that the LV is in the
shape of a prolate ellipsoid. Instead the volume is
broken up into circular slices or cross-sections of
5   predetermined thickness. This method, known as
Simpson's Rule, allows the calculation of a
irregularly shaped chamber such as when the LV has
an aneurysm. The combined volume of the circular
slices is equal to the volume of the LV.
10   To aid in these calculations it is sometimes
desirable to display the information (128). In
addition to the typical CRT display, the display may
also take the form of plotters and printers, for
example. It should be noted that the display can be
15   effected from the information attained at any of the
steps 118, 120 and 126, should the operator so
desire.
In accomplishing the calculation, it is sometimes
desirable to look at successive heartbeats in order
20   to obtain the systolic and diastolic conditions.
However, the number of successive heartbeats needed
to calculate the desired results according to the
present invention is considerably smaller than the
number needed in nuclear medicine techniques or
25   cardiographic techniques, for example.
In addition to calculating the ejection fraction,
it is also possible to obtain data sufficient to
analyze a large number and variety of heart
functions, many of which have been extensively
30   described in the relevant literature.
A presently preferred embodiment of the present
invention has been described above with a degree of
specificity. It should be understood, however, that
this description has been made by way of preferred
35   example and the invention itself, however, is
defined by the scope of the appended claims.

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THE INVENTION CLAIMED IS:

1. A method of ultrasonically determining the movement of a pool of blood in an organ of a human body, comprising:

    transmitting an ultrasonic signal into the moving blood pool and the organ in the human body;

    receiving a reflected ultrasonic signal reflected by the moving blood pool and the moving organ;

    analyzing the reflected signal to obtain movement information indicative of the movement of the pool of blood and the movement of the organ;

    separating from the movement information that information indicative of a greater rate of movement than the rate of movement of the organ; and

    defining the blood pool from the movement information indicative of a greater rate of movement than the movement of the organ.

2. A method as defined in claim 1 wherein defining the blood pool further comprises:

    creating an image of the blood pool from the movement information indicative of a greater rate of movement than the movement of the organ.

3. A method as defined in claim 1 further comprising:

    using the separated information to determine the size of the moving pool of blood.

4. A method as defined in claim 2 further comprising:

    selecting a range of limits for rates of movement to be used in coloring the created image, using the movement information;

    coloring the portions of the created image with a first color representative of movement in one direction and within the selected range;

    coloring the portions of the created image with a second different color representative of

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movement in an opposite direction of the one
direction and within the selected range;

      coloring the portions of the created image
with a third color representative of movement in the
5   one and the opposite directions which is out of the
selected range; and

      using the portions of the created image
which are colored with the third color to determine
the size of the moving pool of blood.

10   5.   A method as defined in claim 4 further
comprising:

      automatically detecting the boundaries of
the portions of the created image which are colored
with the third color.

15   6.   A method as defined in claim 5 further
comprising:

      automatically determining the volume of the
blood pool from the boundaries of the portions of
the created image which are colored with the third
20   color.

     7.   A method as defined in claim 2 further
comprising:

      selecting a range of limits for rates of
movement to be used in coloring the created image,
25   using the movement information;

      coloring the portions of the created image
with a color representative of rates of movement
which are out of the selected range; and

      using the portions of the created image
30   which are colored to determine the size of the
moving pool of blood.

     8.   A method as defined in claim 7, further
comprising:

      selecting a range of limits for variations
35   in the rates of movement to be used in coloring the
created image, using the movement information; and

coloring the portions of the created image
with a color which represents both the rates of
movement which are out of the selected range of
rates and the variations in the rates of movement
which are out of the selected range of variations.

9.   A method as defined in claim 3 further
comprising:

determining the size of the pool of blood in
a systolic condition;

determining the size of the pool of blood in
a diastolic condition; and

.evaluating the performance of the organ by
comparing the determined sizes of the pools of blood
in the systolic and diastolic conditions.

. 10.   A method as defined in claim 9 further
comprising:

determining a fractional relationship
defined by the difference in size of the determined
sizes of the pools of blood in the systolic and
diastolic conditions relative to either one of the
determined size of the pool of blood in the systolic
or diastolic conditions.

11.   A method as defined in claim 10 wherein the
organ is the heart and the fractional relationship
is the ejection fraction of the left ventricle of
the heart.

. 12.   A method of imaging moving pools of blood in
a human body with ultrasound, comprising:

transmitting an ultrasonic signal of a
predetermined frequency into a human body;

receiving a reflected ultrasonic signal from
the human body;

continuously sweeping the direction of the
transmitted ultrasonic signal through a scan angle
comprising a predetermined arc;

comparing the reflected signal to the
transmitted signal to determine a difference in

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frequency therebetween and an elapsed time between
the time of transmission and the time of reception;

generating a color image based upon the
difference in frequency, the elapsed time and the
5   scan angle, wherein a frequency shift in one
direction is represented by a first color and a
frequency shift in an opposite direction is
represented by a second color; and

determining the uncertainty of the frequency
10 shift based upon sampling theory and representing
all such uncertain received signals as a third
color.

13. A method as defined in claim 12, further
comprising:
15   displaying said color image.

14. A method as defined in claim 12, further
comprising:

processing said color image to determine:

the edges of regions of the third color
20 in the image,

a magnitude of the two-dimensional area
of said regions; and

a magnitude of the three-dimensional
volume of said regions in the human body.
25   15. A method as defined in claim 14, further
comprising:

displaying said magnitude of the three-
dimensional volume of said region on a display.

16. A method as defined in claim 14 wherein each
30 step of the method is repeated at a subsequent time
to determine the change in the magnitude of the
three-dimensional volume of said region.

17. A method as defined in claim 16, further
comprising:
35   displaying said change in the magnitude of
the three-dimensional volume.

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18. An apparatus for imaging moving pools of
blood in a human body with ultrasound, comprising:
        means for transmitting a series of
ultrasonic signals of a predetermined frequency into
5   the human body;
        the series of ultrasonic signal reflecting
from tissues and fluids within the human body to
create a series of echo signals which are received
by the apparatus and which have a frequency
10   different from said transmitted frequency by an
amount proportional to the velocity of said tissues
and fluids from which said series of transmitted
signals were reflected;
        processor means receptive of the series of
15   echo signals for:
            calculating the range, position and
velocity of said tissues and fluids within the human
body,
            categorizing by velocity each
20   resolvable element of said tissues and fluids;
            determining an area of tissues and
fluids having a velocity with a magnitude relativity
higher than the surrounding tissues and fluids; and
            estimating the three-dimensional volume
25   of said determined area of tissues and fluid.
        19. Apparatus as defined in claim 18, further
comprising:
            display means connected to said processor
means and operative for displaying said estimated
30   volume.
        20. Apparatus as defined in claim 19, wherein
said processor means further performs said
calculation, categorization, determination and
estimation functions at a subsequent time to
35   determine a change in the three-dimensional volume.
        21. An apparatus for imaging moving pools of
blood in a human body with ultrasound, comprising:

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means for transmitting a series of ultrasonic signals of a predetermined frequency into the human body;

the series of ultrasonic signal reflecting
5   from tissues and fluids within the human body to create a series of echo signals which are received by the apparatus and which have a frequency different from said transmitted frequency by an amount proportional to the velocity of said tissues
10   and fluids from which said series of transmitted signals were reflected;

processor means receptive of the series of echo signals for:

calculating the range, position and
15   velocity of said tissues and fluids within the human body,

generating a color video signal containing said range, velocity and position information; and
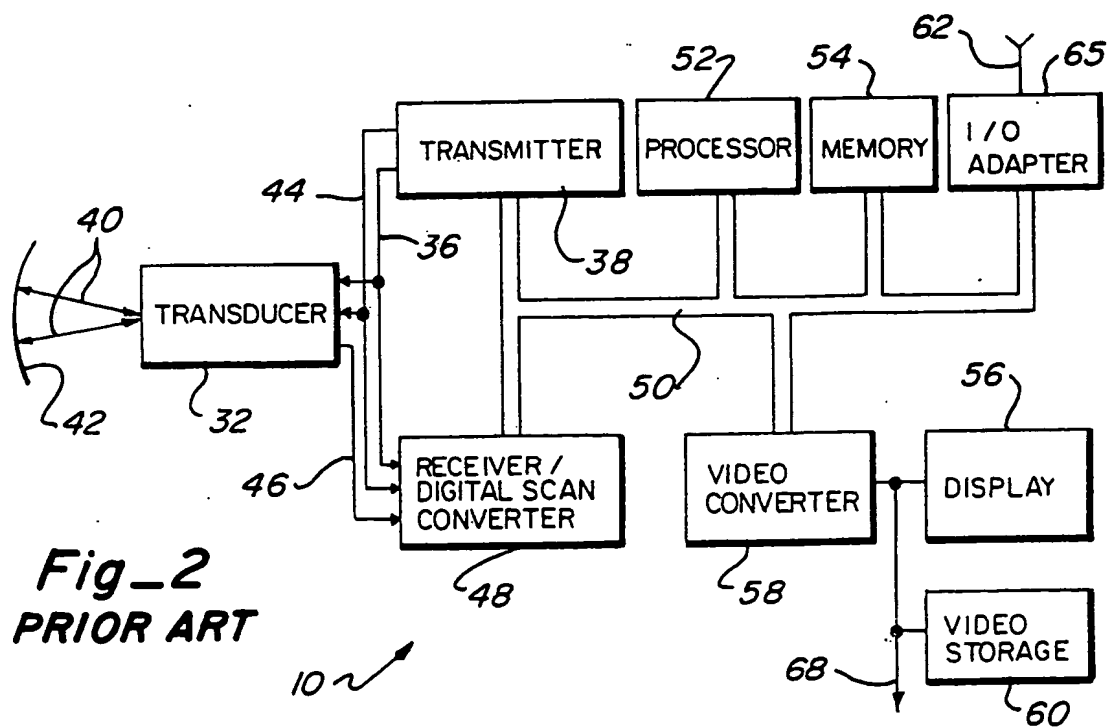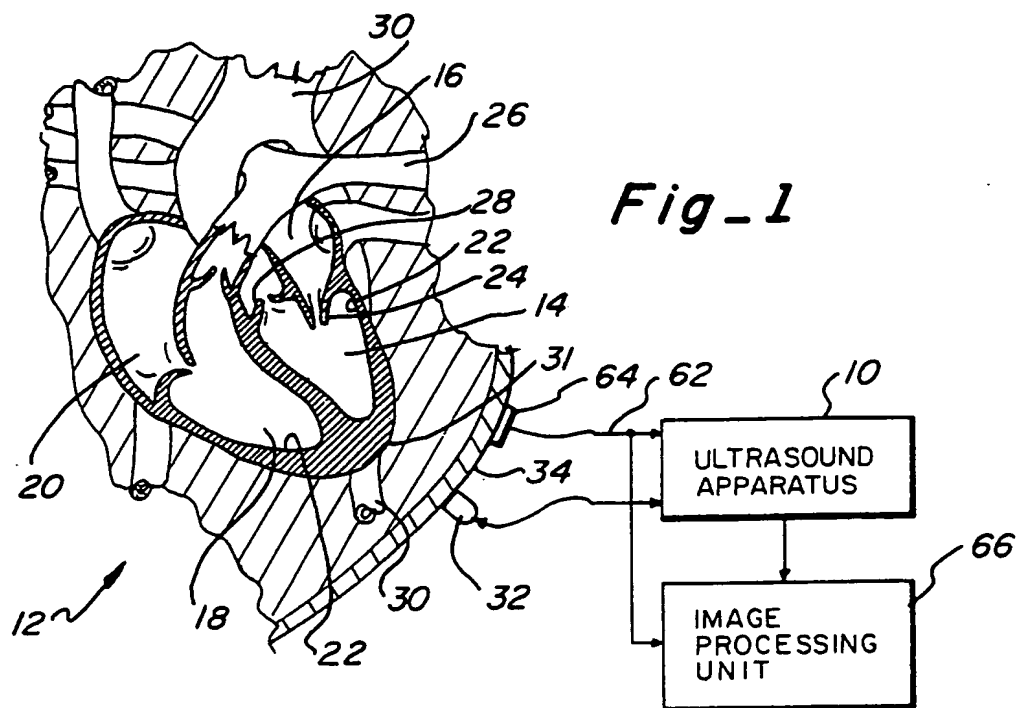20   adjusting the color representing each tissue and fluid in said color video signal to assign a distinct color to tissues and fluids having a velocity with a magnitude relatively higher than the surrounding tissues or fluids.
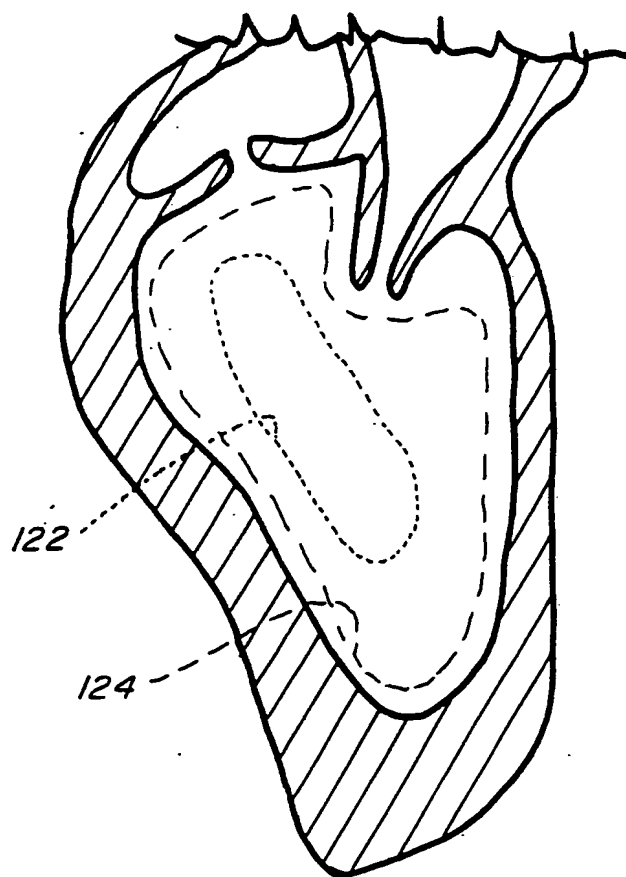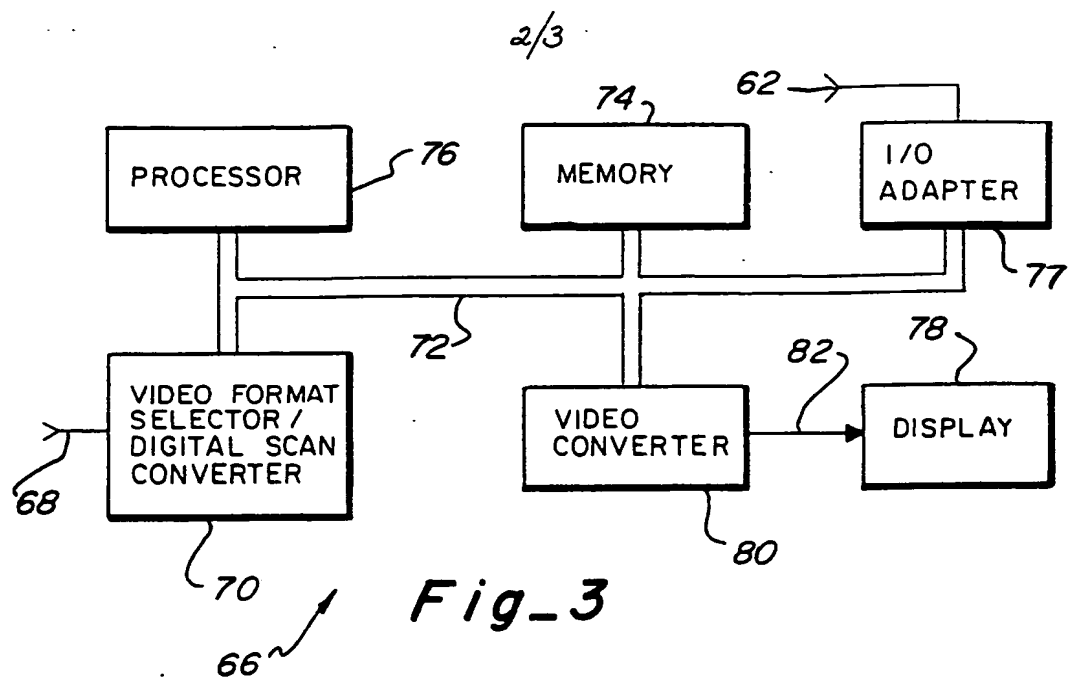
25   22. Apparatus as defined in claim 21, further comprising:

display means receptive of said color video signal and operative for displaying a color image based on said color video signal.

30

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Fig_1

Fig_2
PRIOR ART

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Fig_3

Fig_5

100 START

102 POSITION PROBE

104 SELECT COLOR FLOW

106 SELECT REGION OF INTEREST

108 SELECT VELOCITY FLOW RANGE FOR HEART WALL MOVEMENT EG. 8-17 cm/s

110 ADJUST VELOCITY FLOW RANGE FOR MAXIMUM OUT-OF-LIMIT RESPONSE I.E. MAXIMUM ALIASING, VARIANCE, PHASE SHIFT

112 ADJUST PROBE POSITION FOR DESIRED VIEW

114 GATE FRAMES FROM EKG WAVE

116 DIGITIZE, ANALYZE FRAME SIGNALS

118 RECORD FRAME DATA AND COLOR FLOW INFORMATION

120 DETECT EDGES OF MOVEMENT FROM OUT-OF-LIMIT RESPONSE

126 CALCULATE RESULTS USING DETECTED EDGE MOVEMENT DATA

END

DISPLAY

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Fig_4

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)

According to international Patent Classification (IPC) or to both National Classification and IPC

IPC(5): A61B 8/02
US CL : 128/661.07

I. FIELDS SEARCHED

Minimum Documentation Searched

Classification System	Classification Symbols
U.S.	128/661.07,661.08,661.09,661.10,661.04,916

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are included in the Fields Searched

III. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A,P	US, A, 5,052,395 (BURTON ET AL.) 01 OCTOBER 1991 See entire document.	1-22
A	US, A, 4,095,597 (HASSLER) 20 JUNE 1978 See entire document.	1-22
A	US, A, 4,257,278 (PAPADOFRANGAKIS ET AL.) 24 MAY 1981 See entire document.	1-22
A	US, A, 4,858,614 (STEVENS ET AL.) 22 AUGUST 1989 See entire document.	1-22
A	US, A, 4,785,402 (MATSUO ET AL.) 15 NOVEMBER 1988 See entire document.	1-22
A	US, A, 4,966,150 (ETIENNE ET AL.) 30 OCTOBER 1990 See entire document.	1-22
A	US, A, 4,873,985 (NAKAJIMA) 17 OCTOBER 1989 See entire document.	1-22

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
23 JANUARY 1992	27 FEB 1992

International Searching Authority	Signature of Authorized Officer
ISA/US	G. MANUEL NGUYEN NGOC-BO INTERNATIONAL DIVISION

Form PCT/ISA/210 (second sheet) (Rev.11-87)